Data Mining Techniques Applied to Urban Terrain Command and Control Experimentation

Track: C2 Experimentation

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Abstract

Advances in the fields of simulation and data mining are proving relevant to providing battlespace decision support. High performance computing, improved modeling techniques, and new decision support methodologies drive these advances. Combat simulations now generate behaviors at increasingly finer scales. Data mining provides a mechanism for uncovering key patterns in larger data sets such as those generated by modern combat simulations. The capability of simulating detailed courses of action (COAs) opens up the possibility of mining collected data for insights. Specifically, decision support systems could assist commanders in examining simulation data for relationships between the structure of the COA and various battle objectives. Our current experimentation centers on the use of complex or urban terrain for warfighting. The synergy of data mining tools, high performance computing, and high resolution simulation has the potential to assist battle planners in the improvement of battlefield assessments and the expedient modification of COAs.

I. Introduction

Advances in the fields of simulation and data mining can provide commanders with relevant battlefield planning insights. Data mining provides a mechanism for uncovering key patterns in larger data sets such as those generated by modern combat simulations. At both the Command and Control Research and Technology Symposium (CCRTS) and the International CCRTS of 2002, the Battlespace Decision Support Team (BDST) of the U.S. Army Research Laboratory (ARL) advanced a technique for course of action (COA) evaluation. Before a battle, the model provides a rich information environment that can enhance the commander's decisions during battle planning and execution. This environment features the intricacy and uniqueness of battlefield parameters, such as the types of effective ammunition. Refined information, based on these raw battlefield parameters, is a synthesis of various data mining techniques applied to the results of high fidelity simulation.

Our prior work successfully demonstrated the relationship of key battlefield parameters to battle outcome, thereby suggesting a basis for enhanced decision-making. The original experiment used a small Southwest Asia scenario, portraying a traditional conflict of tank on tank. However, we realize the environments of current and future conflicts, including urban and other complex terrains, do not readily support traditional warfighting methods. For our current experiment, we use an urban setting and incorporate dismounted troops in tactical combat. We will also attempt to consider robotic influences, depending on the availability of robotic models within our combat simulation at experimentation time.

The varied nature of urban terrain presents significant challenges to the command staff during planning and execution. Information requirements within an urban conflict are extremely time-critical, as combat occurs over very short time periods and terrain

changes make navigation uncertain. A future program goal is to provide commanders with a planning model that enables quick exploration of varied combat options when faced with developing COAs for urban combat.

A key to our planning methodology is to assist the commander in the creation of logical branches and sequels that address battlefield occurrences. Using computer simulations and data mining approaches, our techniques will provide both comprehensive and expedient planning analysis. In future applications, we will incorporate soldier combat reports directly into a simulation-based planning system to ensure the use of accurate situational awareness in the creation of re-planning products. Once perfected, commanders will be able to rely on our analysis products when choosing alternatives for their soldiers in combat, thus shaping the battle faster than their opponents and forcing the enemy to react to the defined plans. Our approach will enable commanders to capture and retain battlefield initiative on difficult urban terrain. The current experiment will apply our analytic approach to an urban combat scenario.

II. Military Operations in Urban Terrain (MOUT)

A country's center of mass is its cities. Cities are vital to any country's political, technical, and economic operations. Traditionally, urban environments provide vital sources of raw materials, personnel, and manufactured goods for military forces in the conduct of war. The famous military philosopher Sun Tzu believed a military force should only attack cities when no other alternative existed.[1] However, Lt. Col. Robert R. Leonhard argues that this is "Bad advice [for] urban warfare in the information age." He points out that urban terrain is becoming the norm as nations become more technologically advanced.[2] In fact, if current population predictions hold, upwards of 85% of the world's population will live in cities by the year 2025.[3] It will be difficult to execute a future war without conducting some actions in complex and urban terrain.

The most recent example is the war between the coalition forces led by the United States and the forces of Saddam Hussein in Iraq. Iraq's terrain consists of open desert with some tropical areas near the more fertile parts of the country. While coalition forces met some resistance in the open desert, particularly near installations of economic importance such as oil fields, the resistance was quickly overwhelmed. Faced with a disadvantage in the open, Iraqi forces chose to defend urbanized areas where they could better the odds by using a city's natural defensive terrain.

In the cities, coalition forces faced a daunting task. To finally defeat Iraq, coalition forces had to control the centers of commerce and government. The only way to do this was to give away some advantages and accept battle in the cities themselves. For example,

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[1] Sun Tzu, The Art Of War, Translated by Thomas Cleary, (Boston, MA Shambhala Publications, Inc., 1988), p. 70.
[2] Lt. Col. Robert R. Leonhard. AUSA *Army Magazine*, http://www.ausa.org/armymagazine; Internet, accessed 23 April 2003.
[3] Department of the Navy, Headquarters United States Marine Corps. "Military Operations on Urbanized Terrain (MOUT)," Marine Corps Warfighting Publication 3-35.3, p. 1-1.

coalition forces effectively lost the advantages of outranging the enemy when they entered the cities of Iraq.

Operations within urban terrain pose challenges by their very nature: fighting close due to urban clutter and operations in the three-dimensional space of the street level, building stories, and underground structures.[4] Our next experiment will explore urban combat by incorporating the insights of historical and current battlefield techniques with our methodology for assisting in the development of military courses of action. We intend to incorporate a different set of battlefield parameters in this experiment, to enhance planning aids for commanders in the challenging urban environment.

III. Scenario Development

The experimental scenario will feature many of the tenets currently found to be effective in MOUT for both the offense and the defense. United States units will be present as the offensive force facing a grouping of former Soviet-style units in defensive positions. A sector of a city, based on the McKenna MOUT site, Fort Benning, GA, will dominate the terrain used in the scenario.

A version of the One Semi-Automated Forces (OneSAF) Test Bed (OTB) combat simulation, designated the Dismounted Infantry Semi-Automated Forces (DISAF), will provide the medium for scenario development and the data for subsequent analysis. DISAF provides a detailed rendition of close fighting conditions found in urban terrain and focuses on individual combatants; both factors are necessary for the experiment we propose.

The scenario consists of a company attack on a city sector carried out in two distinct phases. Phase 1 consists of the company attack to isolate the area. Swift movement characterizes the attack, which consists of a two-pronged encirclement to drive threat forces from positions around the sector, as shown in Figure 1. A platoon of mechanized infantry defends the area. It is set to offer maximum resistance to an encirclement attack with a concentration of forces both inside the sector and in the wooded area to the East. The sector is too small to offer much cover, but the enemy forces will defend this political objective to the end.

Historically, a force that isolates a city will eventually control it. Many times in the past, a fiercer resistance occurred during the operation to isolate a city than actual fighting for control of the city itself. When a defending force loses the ability to freely use the resources of a city, that city becomes untenable and loses real value. Yet defenders may choose to fight in a city because the natural clutter of cities, coupled with their multi-dimensional nature, gives the defender many advantages. Defenders will know that storming a city is usually an expensive proposition for the attacking force and will use an active defense to dissuade an attack and ultimately to disrupt the attacker's timetable. In

[4] Department of the Navy, Headquarters United States Marine Corps. "Military Operations on Urbanized Terrain (MOUT)," Marine Corps Warfighting Publication 3-35.3, p. 1-3.

this scenario, the communication routes (road infrastructure) and strategic importance of the sector to local politics call for a direct attack in the MOUT environment.

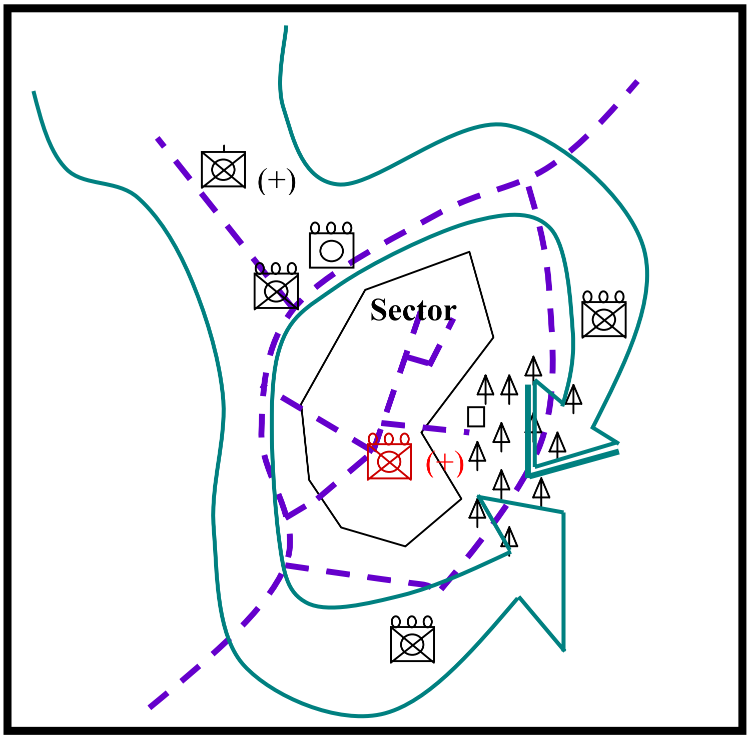

Figure 1: Scenario Phase 1 MOUT assault

Phase 2 of the scenario features an all-direction assault of the area. The attack is a coordinated plan with a mixture of infantry and tanks in the main effort. The objective is to control the key facilities inside the town. This attack features a maximum shock effect. The threat cannot defend well from every angle and should be overwhelmed when confronted in this manner.

Historically, city attackers have fared the best when executing a plan that features combined arms. The marriage of tanks and infantry is a deadly combination. In fact, in spite of the defensive properties of a city, nearly 95% of attacks on cities are successful.[5] Sometimes, however, the cost of the victory is that winning a city fight can be tantamount to losing a campaign.

Victory in our scenario hinges on the number of key buildings controlled after the assault. Using a reasonable attacker-to-defender force ratio of 3:1, our scenario will result in a distribution of victory and loss for both sides and provide a rich source of data for subsequent analyses.

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[5] Department of the Navy, Headquarters United States Marine Corps. "Military Operations on Urbanized Terrain (MOUT)," Marine Corps Warfighting Publication 3-35.3, p. 1-13.

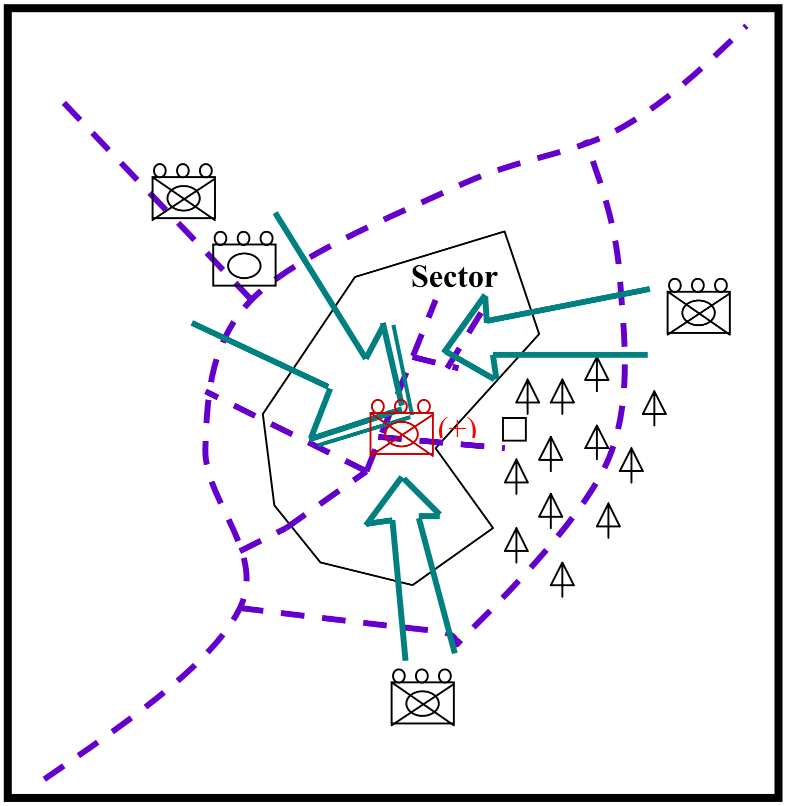

Figure 2: Scenario Phase 2 MOUT assault

IV. Experiment

The experimental objective is the discovery of battle parameter relationships to assist a commander in the planning and execution of urban military missions. Data collected from scenario runs is key to providing parameters from which we can build a composite planning metric using statistical methods. By adjusting the plan to address success in the composite parameters, commanders will better ensure success in operations.

To allow for efficient data collection through a number of scenario executions, we will insert a set of code changes into DISAF known as a "killer/victim scoreboard" (KVS). The operation of KVS code collects data, such as entity exchanges of fire and logistics usage, into a reusable, time stamped data file.[6,7] Further, we will use a set of UNIX™ shell scripts to divide the time stamped data into a set of files each containing a rollup of different battlefield aspects or parameters. For example, one parameter is the amount of a type of ammunition used in a scenario run.

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[6] Eric Heilman and Janet O'May. "A OneSAF Data Collection Methodology," US Army Research Laboratory Technical Report, AR-TR-2663, February 2002.
[7] Eric Heilman and Janet O'May. "OneSAF Killer/Victim Scoreboard Capability," US Army Research Laboratory Technical Report, AR-TR-2829, September 2002.

Several statistical methods will support our efforts to find significant parameters. These include linear regression and classification and regression trees. The response variable will measure an attacking force win or loss dependent upon buildings occupied at the conclusion of each scenario run. The chosen statistical method will determine the amount of data and the number of actual scenario executions necessary to gain an understanding of important composite metrics.

V. Preliminary Conclusions

Currently, we have not yet made the decision on which statistical techniques to use for the experiment. We have compiled the DISAF combat simulation on our local machines and are now inserting the data collection KVS code. We expect to run the MOUT experiment in Summer 2003.

Given the battles of operation Iraqi Freedom, we have moved our efforts to the timely topic of MOUT. COA development for this environment is difficult due to the nature of the terrain. We feel that commanders can gain a better understanding of MOUT planning using our classification and prediction techniques. We hope that by addressing the elements embedded in composite metrics commander will improve their forces' ability to operate successfully in urban terrain.

We have compiled the DISAF combat simulation on our local machines and are now inserting the data collection KVS code and considering which statistical techniques to use for the experiment. We expect to run the MOUT experiment in Summer 2003. Commanders will gain a better understanding of MOUT planning by using our classification and prediction techniques. By addressing the elements embedded in composite metrics, commanders will improve their forces' ability to operate successfully in urban terrain.

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Heilman, Eric G. and Janet O'May. ARL-TR-2829, OneSAF Killer/Victim Scoreboard Capability, September 2002.

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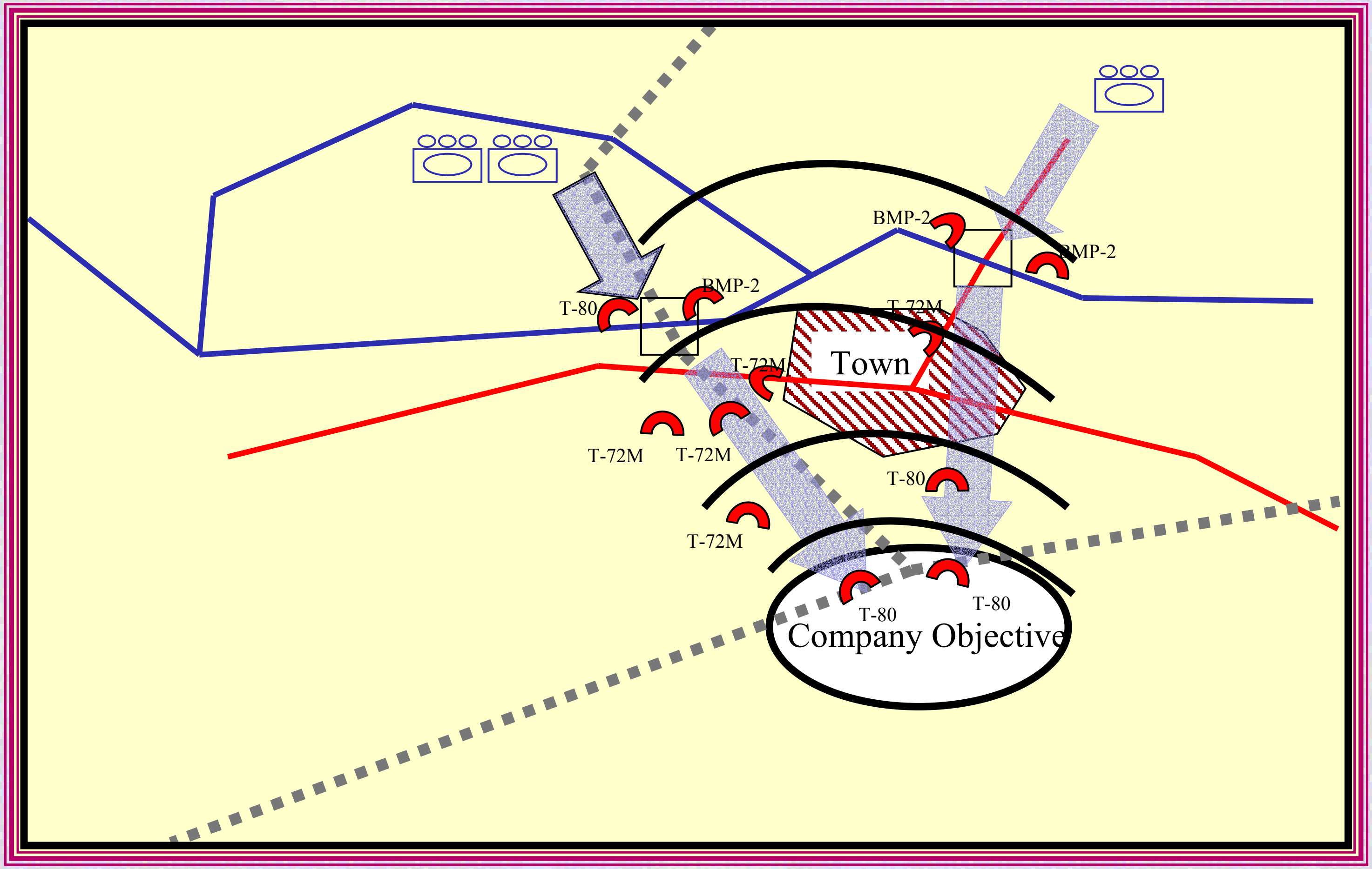
Previous Work

- Simulated Southwest Asia scenario using One Semi-Automated Forces (OneSAF) Testbed Baseline (OTB) for 228 plays of the same battle
- Used a Killer/Victim Scoreboard (KVS) to collect metrics [143 metrics per three time slice]
- Used statistical data mining approaches to relate battle outcome to metrics
- Concluded: great potential for identifying key metrics in the battle worth tracking and/or for suggesting course of action changes

Scenario


BMP-2
BMP-2
BMP-2
T-80
T-72M
T-72M
Town
T-72M
T-72M
T-80
T-72M
T-80
T-80
Company Objective

OneSAF Modification
Killer/Victim Scoreboard

- **Firer and Target Identity and Location**
- **Type of Ammo**
- **Range**
- **Outcome**

```
Time Stamp 1010070890
Vehicle ID 1076
Firer ID 1087
Projectile 1143670848
Firer Position:  X = 220217.00  Y = 146765.00  Z = 12.37
Target Position:  X = 222454.38  Y = 149117.80  Z = 9.99
Vehicle 1076: Hit with 1 "munition_USSR_Spandrel" (0x442b0840)
  Comp DFDAM_EXPOSURE_HULL, angle 19.53 deg Disp 0.889701 ft
  Kill Thermometer is: Pk:1.00, Pmf:1.00, Pf:0.90, Pm:0.80 Pn:0.80
RANGE  3246.773576
r = 0.990835 kill_type = MF
```

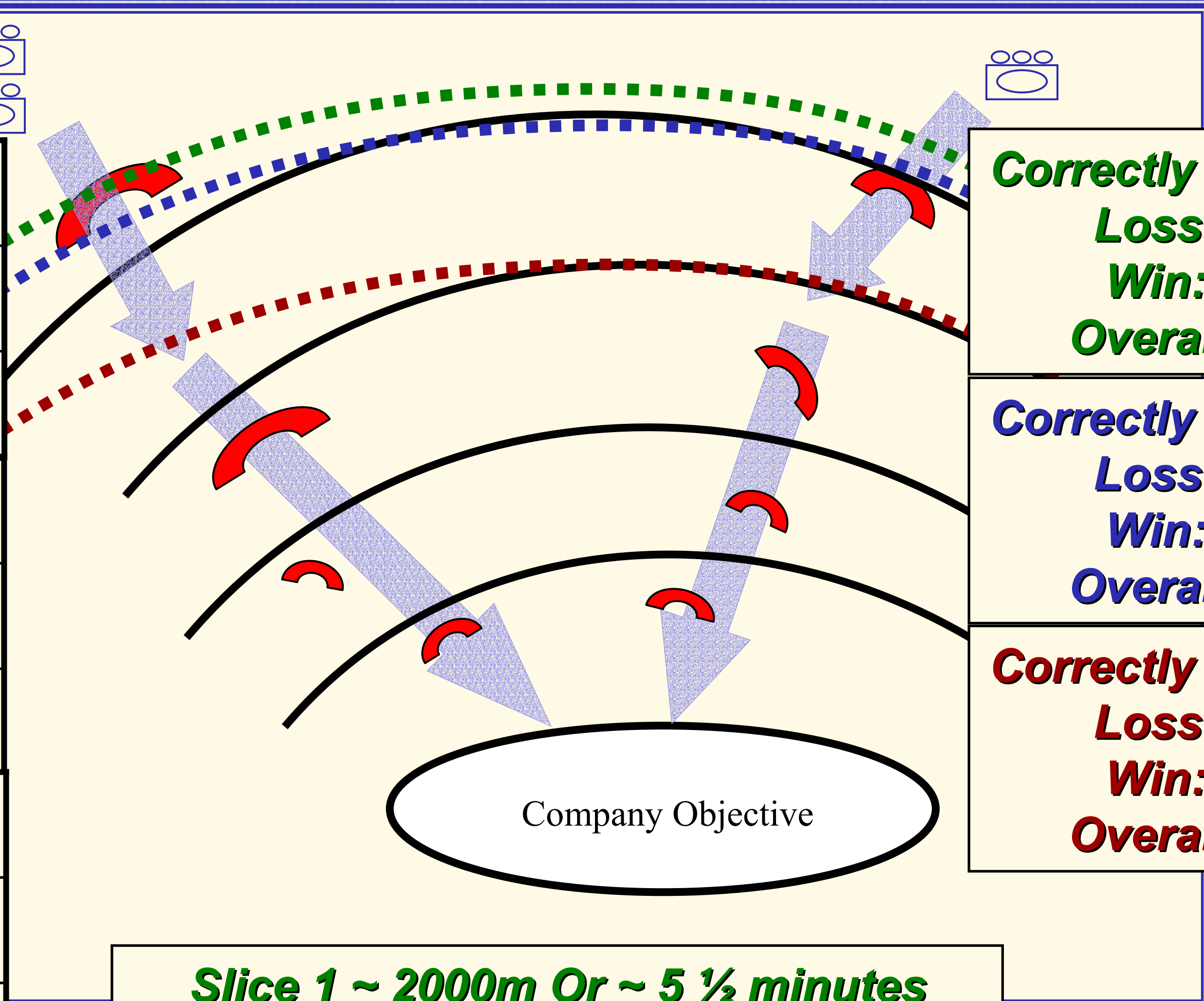
```
1076 100A41 vehicle_US_M1
1087 100A23 vehicle_USSR_BMP2
```

Analysis

Obs \ Pred	0	1
0	85	34
1	35	74

Obs \ Pred	0	1
0	98	21
1	25	84

Obs \ Pred	0	1
0	105	14
1	20	89



Correctly Classified
Loss: 71%
Win: 67%
Overall: 70%

Correctly Classified
Loss: 82%
Win: 77%
Overall: 80%

Correctly Classified
Loss: 88%
Win: 82%
Overall: 85%

Slice 1 ~ 2000m Or ~ 5 ½ minutes

Slice 2 ~ 4000m Or ~ 10 minutes

Slice 3 ~ 5800m Or ~ 20 minutes

Method Comparison

Percent Correct Classification by Stopping Time and Method

Stopping Time (min)	Discriminant Analysis	CART	Logistic Regression
5 ½	70%	70%	69%
10	80%	75%	74%
20	85%	82%	85%

Current Experiment

- Change terrain to urban
- Involve Dismounted Infantry (DI)
- Use Dismounted Infantry Semi-Automated Forces (DISAF) Simulation Software
- Develop urban scenario

DISAF Challenges

- Compiling – need an older version of GNU C and C++ (version 2.91.66)
- KVS Code developed for OneSAF at ARL did not easily insert into DISAF
- Fireteams tend to move better when tasked as individual rather than as a team
- However this breaks down for the “clear room” task which requires a full fireteam
- Vehicles tend to not enter the city sector
- DI entities at times get stuck in buildings and tunnels
- If entities can not determine the proper route they go to the bottom of the terrain

Current Urban Scenario

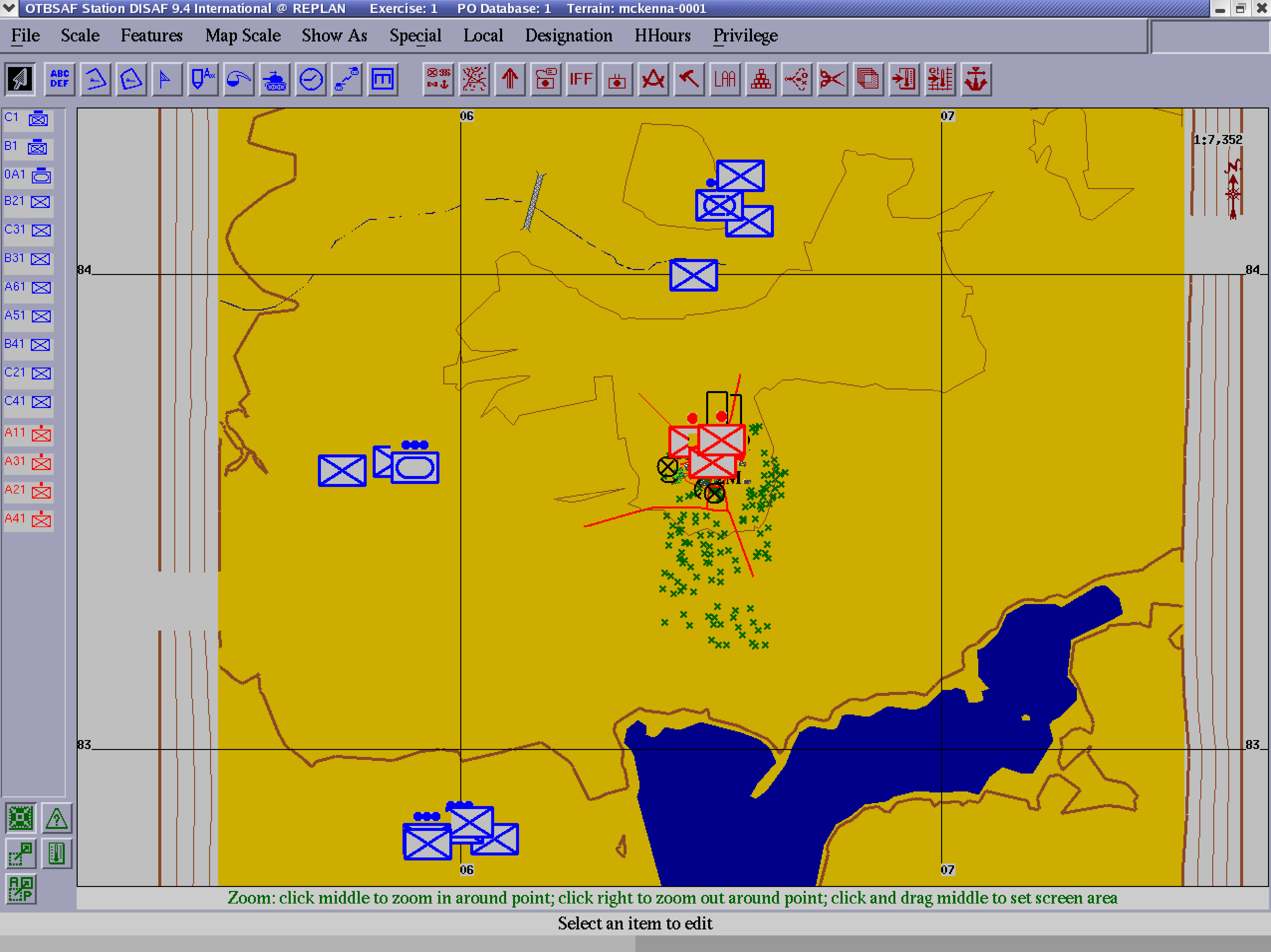
Location: City sector based on the McKenna MOUT (Military Operations on Urbanized Terrain) site

Scenario: Attack Phase I

- Isolate area, three-pronged encirclement to reduce threat forces from perimeter

- Carried out by 2 M2s from the North and 2 M2s from the Southwest and a headquarters (HQ) attachment of 2 M1A1s and 1 M2 entering from the West

- Initial resistance from 3 BMPs and 2 T-80s around the perimeter, a 3rd T-80 is in the center flanking the objective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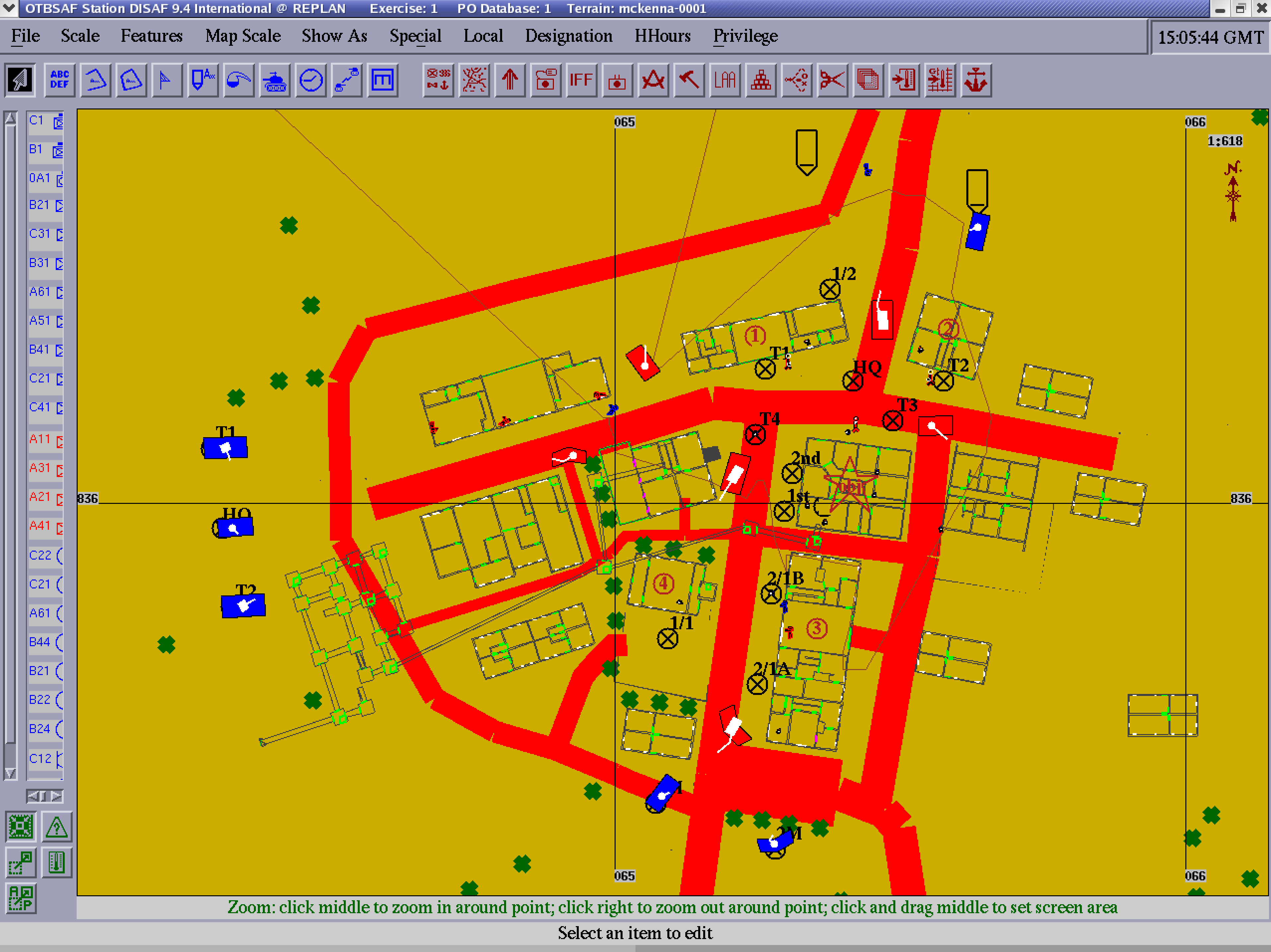
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Current Urban Scenario

Scenario: Attack Phase 2

- Eight fireteams (FT) enter sector behind armored vehicles

- Carried out by 3 FTs from both the North and from the Southwest

- Northern teams clear separate buildings (1 & 2) and continue on to secure objective

- Southwestern teams clear separate buildings (3 & 4) and continue to objective

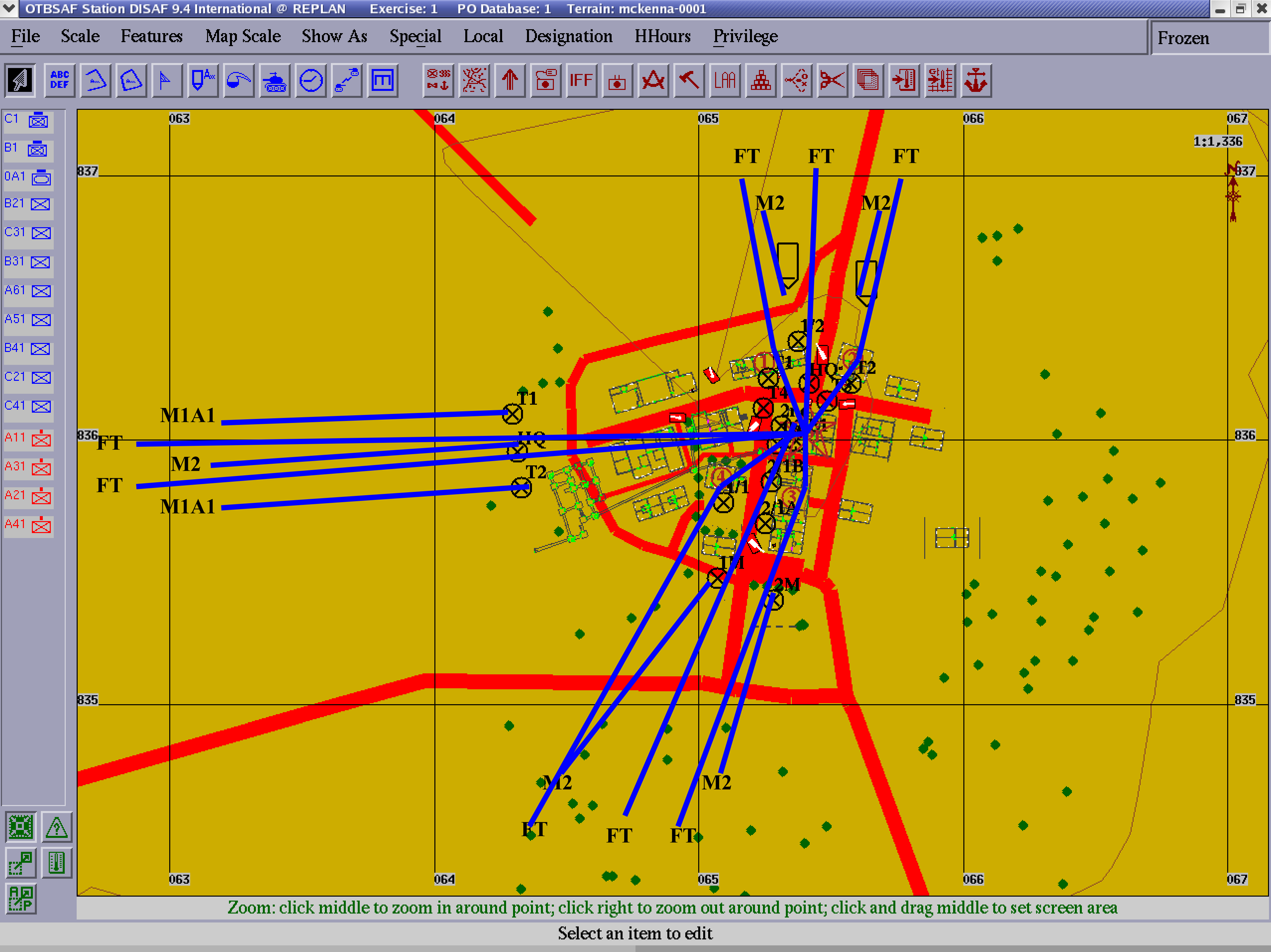
- Two Western FT (HQ) proceed directly to the objective

Current Urban Scenario

Scenario: Attack Phase 2

- Interior resistance provided by opposition DI in the five critical buildings and also in a key vantage point building on the Northwest side of the sector

- Three additional opposition DI stationed outside buildings 1, 2, and the objective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064
065
066
067
837
836
835
1:1,336
FT
M2
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T1
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HQ
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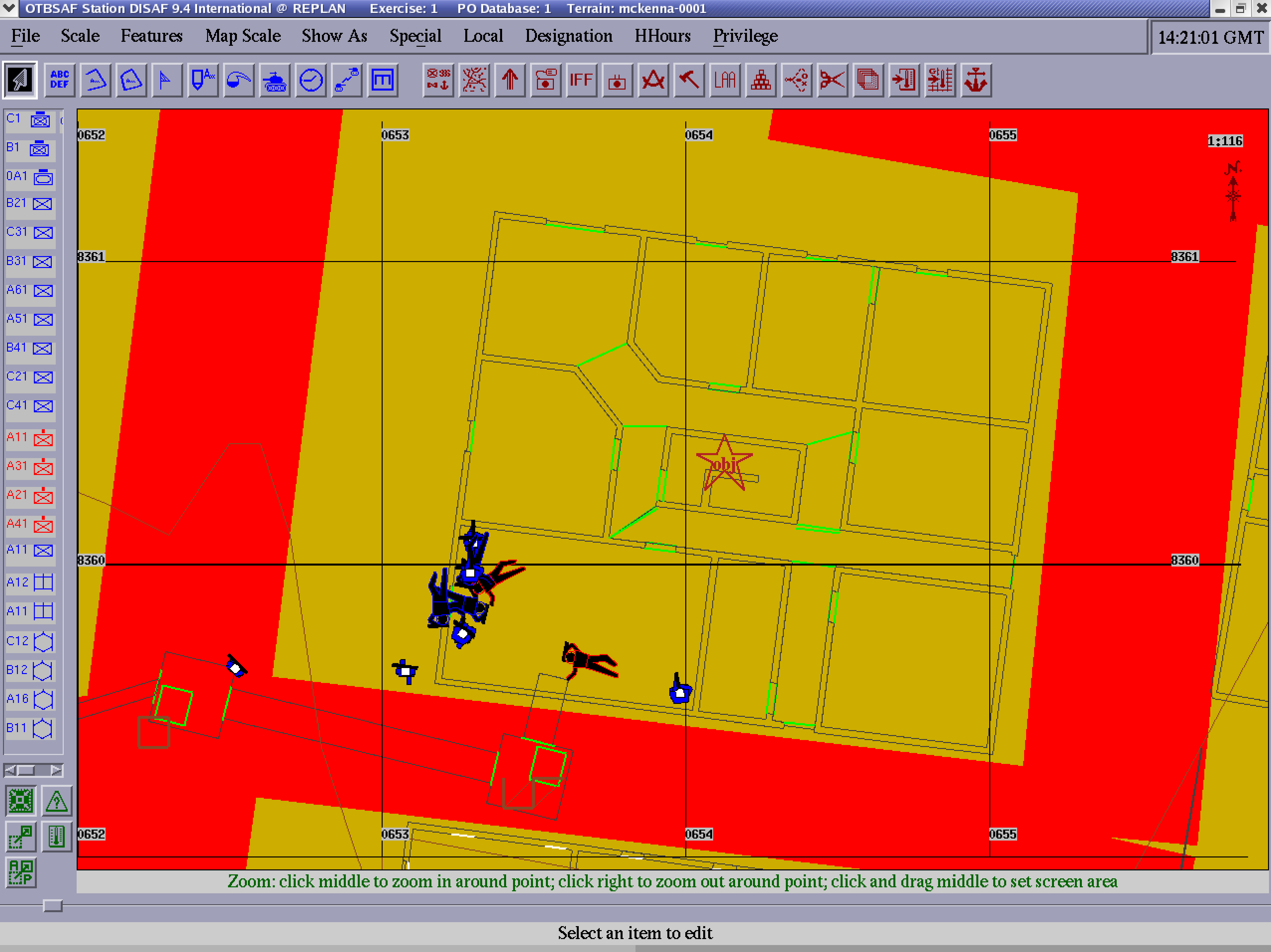
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A41
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8360
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Simulation Data

Predictors

- 444 variables, *but only 75 runs so far*
- Two time slices (372 seconds and 480 seconds)
- Hits taken by Blue and hits by Blue fire involving all relevant vehicles, fireteams, and buildings
- Status of all entities

Responses

- Taking the objective (1 or 0)
- Establishing a foothold in the city (0, 1, 2, 4)
- MOUTscore (0 to 8 with buildings under control with minimum casualties)

Potential Analytical Methods

- Discriminant Analysis
- Cart
- Logistic Regression
- Multiple Regression
- Neural Networks

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A Discriminant Model

Data: Discriminant Function Analysis Summary (FINALMOUTEX1b)*

Discriminant Function Analysis Summary (FINALMOUTEX1b)
Step 7, N of vars in model: 7; Grouping: FootHold (4 grps)
Wilks' Lambda: .32024 approx. F (21,187)=4.3384 p< .0000

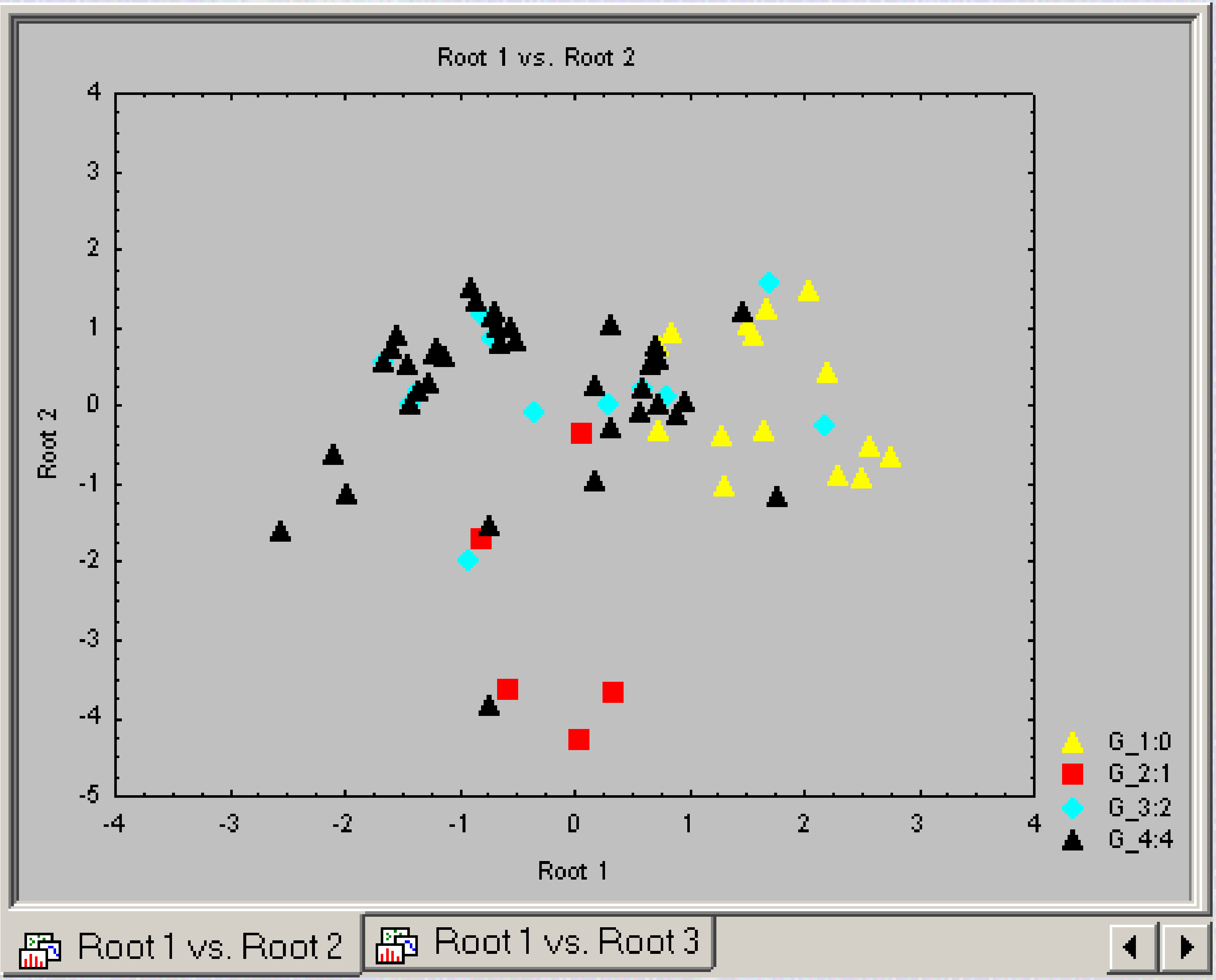
N=75	Wilks' Lambda	Partial Lambda	F-remove (3,65)	p-level	Toler.	1-Toler. (R-Sqr.)
F8TS2	0.488062	0.656143	11.35459	0.000004	0.910182	0.089818
A23TS2	0.380200	0.842291	4.05682	0.010497	0.921236	0.078764
RTA11TS2	0.358180	0.894073	2.56701	0.062007	0.685511	0.314489
BMC12TS2	0.374920	0.854151	3.69965	0.016001	0.877811	0.122189
F5TS2	0.354554	0.903217	2.32167	0.083316	0.967066	0.032934
M3T13FS2	0.344559	0.929415	1.64548	0.187509	0.919428	0.080572
M2A21TS2	0.341595	0.937480	1.44494	0.237843	0.720540	0.279461

Root Means

Group	Means of Canonical Variables (FII		
	Root 1	Root 2	Root 3
G_1:0	1.645990	0.11182	0.072312
G_2:1	-0.182453	-2.73915	-0.044188
G_3:2	-0.273964	0.26408	-0.658511
G_4:4	-0.539702	0.20524	0.207078

Means of Canonical Variables (FINALMOUTE)

Group Separation



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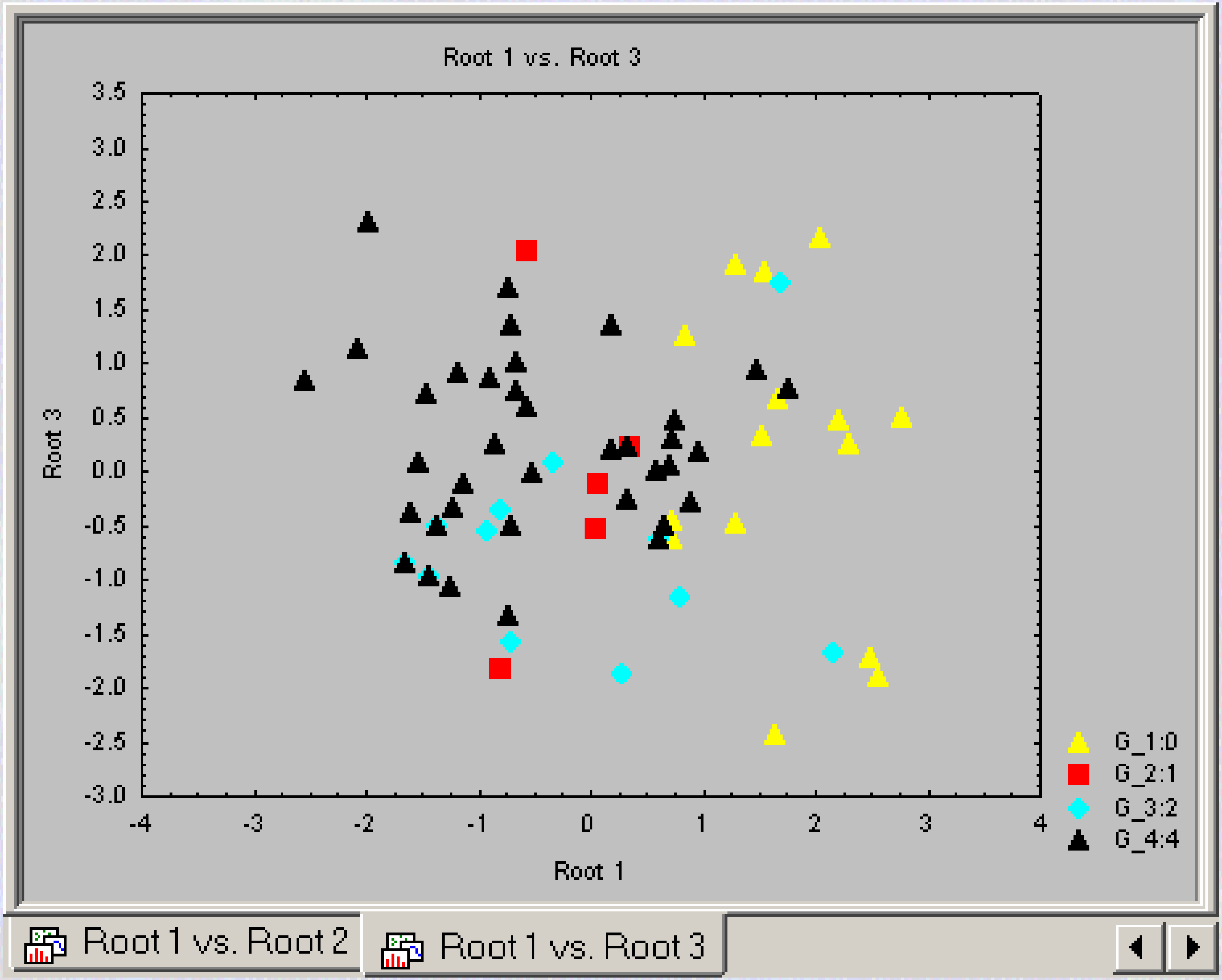

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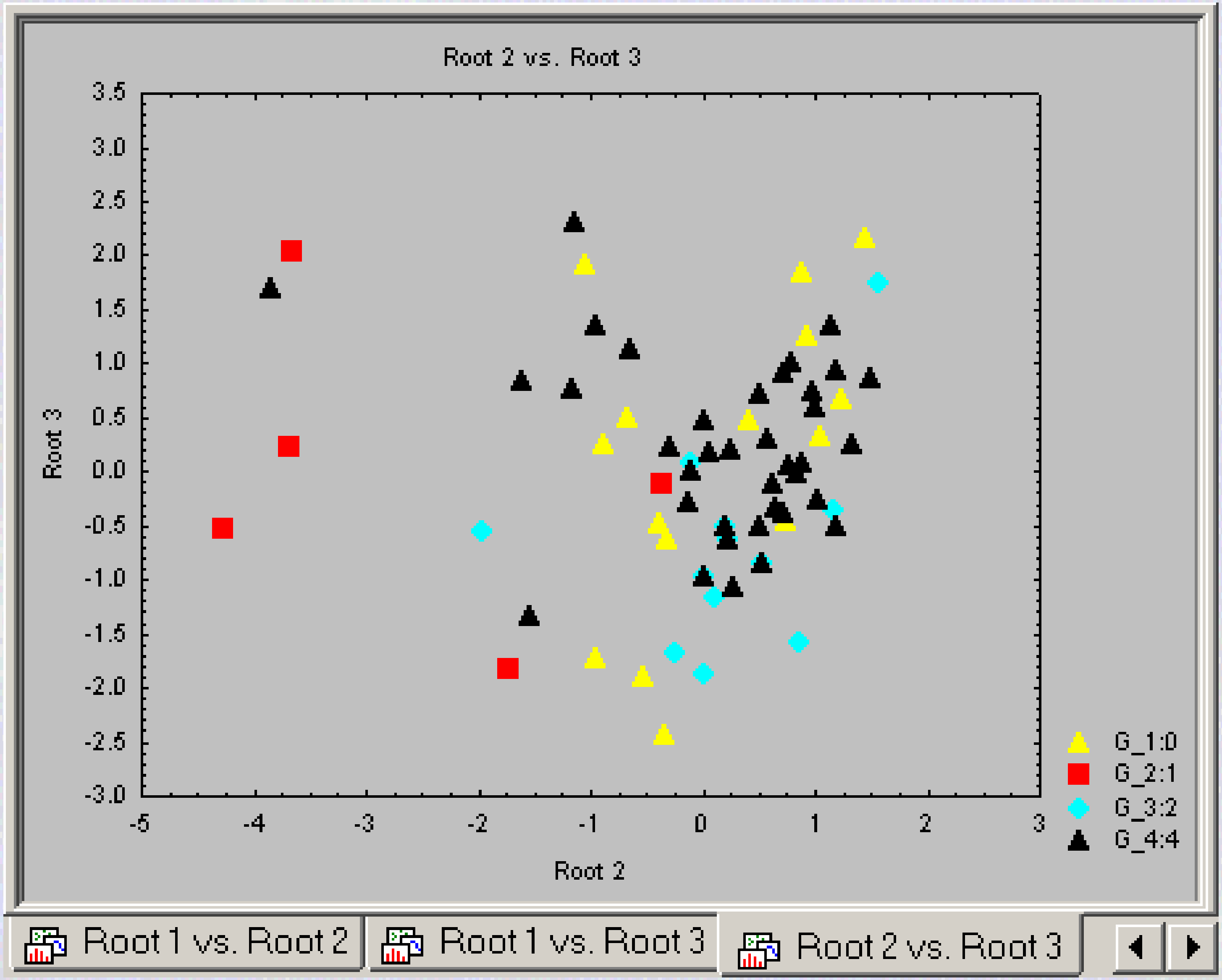


Classification Efficiency

Classification Matrix (FINALMOUTEX1b)
Rows: Observed classifications
Columns: Predicted classifications

Group	Percent Correct	G_1:0 p=.21333	G_2:1 p=.06667	G_3:2 p=.18667	G_4:4 p=.53333
G_1:0	75.00000	12	0	0	4
G_2:1	60.00000	0	3	1	1
G_3:2	21.42857	2	0	3	9
G_4:4	92.50000	2	1	0	37
Total	73.33334	16	4	4	51

Classification Matrix (FINALMOUTEX1b)

Metric Description

F8TS2-Status of FT 8 (B4) at TS2

F5TS2-Status of FT 5 (A6) at TS2

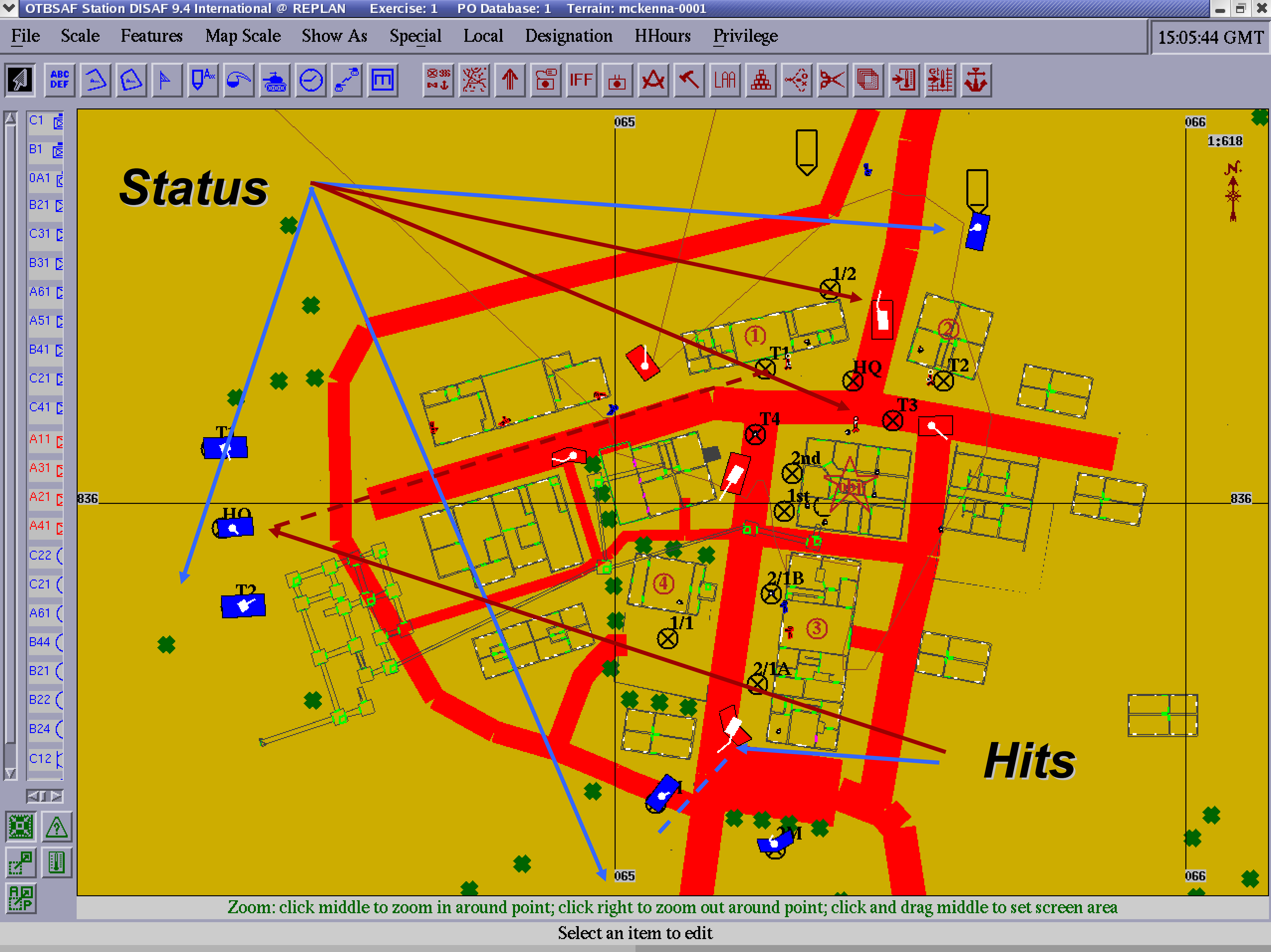
M3T13FS2-Hits by M2-3 (B11, B12) at A13-T80 at TS2

A23TS2-Status of A23-DI at TS2

BMC12TS2-Status of M2 C12 at TS2

RTA11TS2-Status of T80 A11 at TS2

M2A21TS2-Hits taken by M2-2 (A16) by A21-DI at TS2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C22
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A61
B44
B21
B22
B24
C12
065
066
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836
Status
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T4
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Zoom: click middle to zoom in around point; click right to zoom out around point; click and drag middle to set screen area
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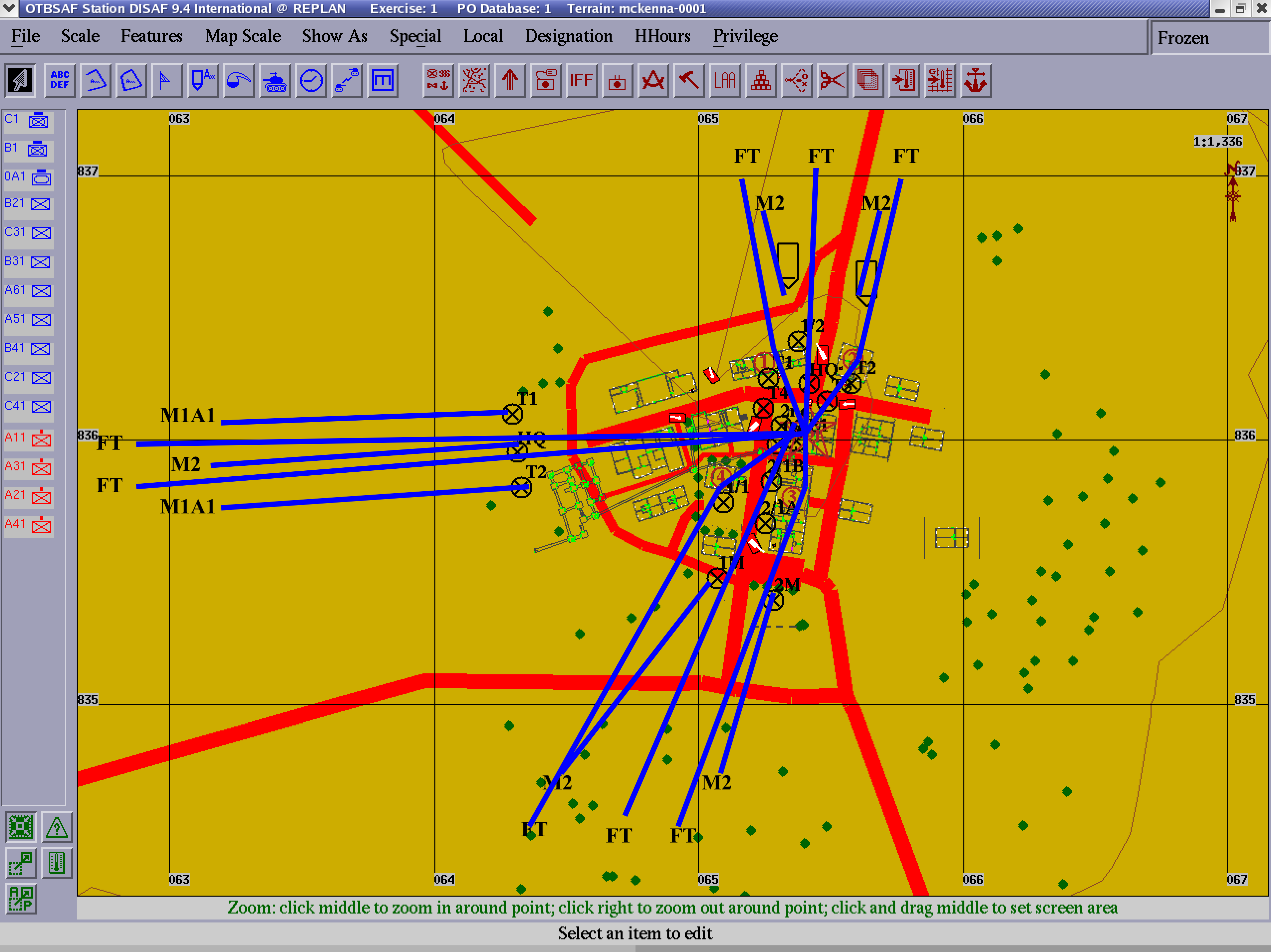

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Zoom: click middle to zoom in around point; click right to zoom out around point; click and drag middle to set screen area
Select an item to edit

Metric Interpretation

FT8 important because mission took it first to Bldg 3 and positioning kept it away from being targeted by Bldg 5

FT5 important because after passing Bldg 5, would move South away from Red DI in approach to objective

M3T13FS2-Hits on T80 – Southwest approach

A23TS2-Status of A23-DI – outside Building 2

BMC12TS2-Status of M2 - Success of North approach

RTA11TS2-Status of T80 on North

M2A21TS2-Hits taken by M2-2 – West approach

Acknowledgements

- Brian Comer of PEO STRI
- Daryl Siddon of SAIC

Without their help, we would never have compiled DISAF!

Directions/Conclusion

- More involved and sophisticated opposition force
- Changes to KVS
- Overall improved scenario
- Establish data from more time periods to provide information on battle progression
- Collect information from a larger number of battles
- Use a greater variety of statistical tools, to include work in the microarray arena
- Data mining combat simulations holds great promise for understanding battles if one believes the simulations and statistical methods will continue to improve.

Questions ???

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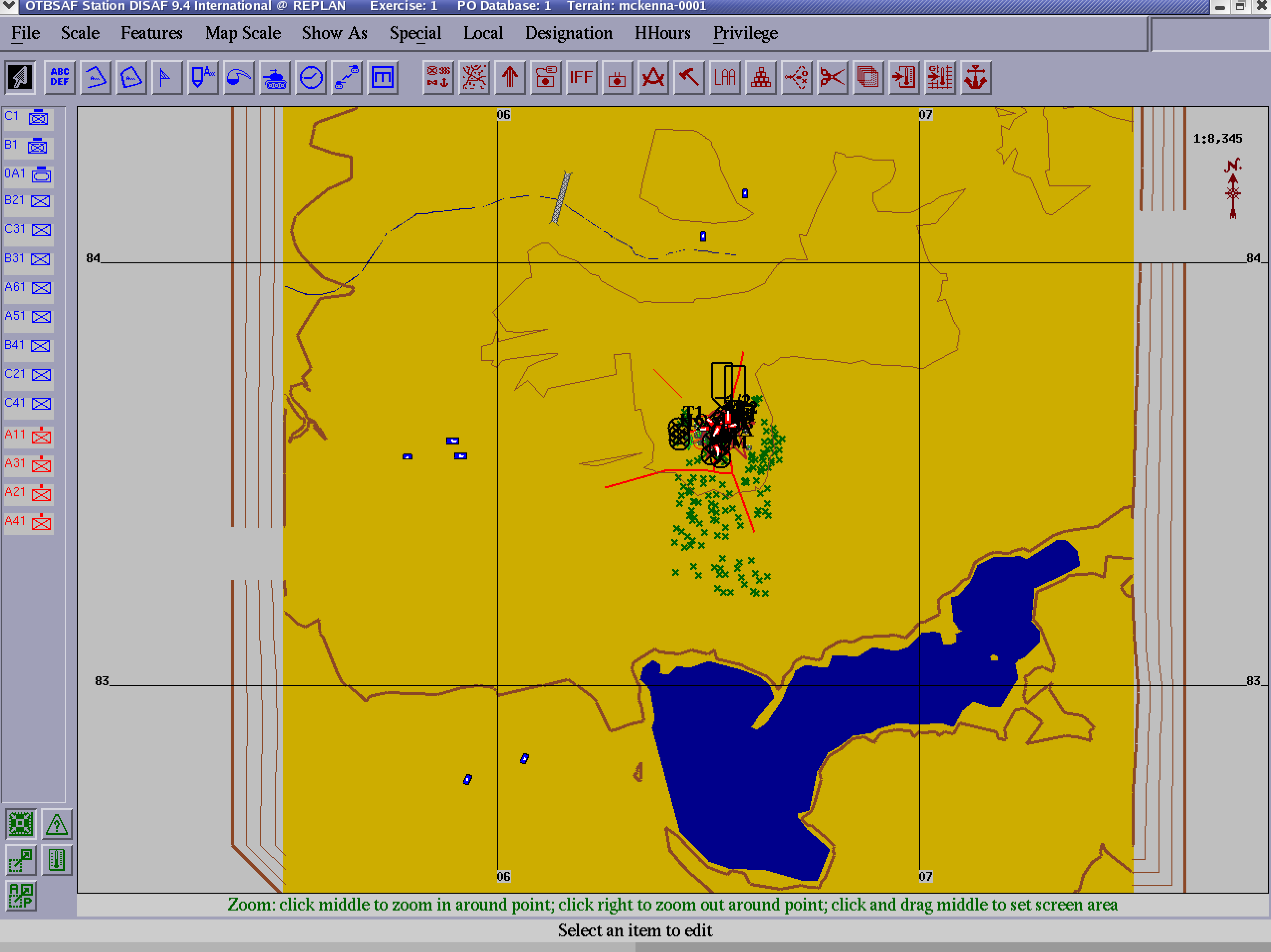
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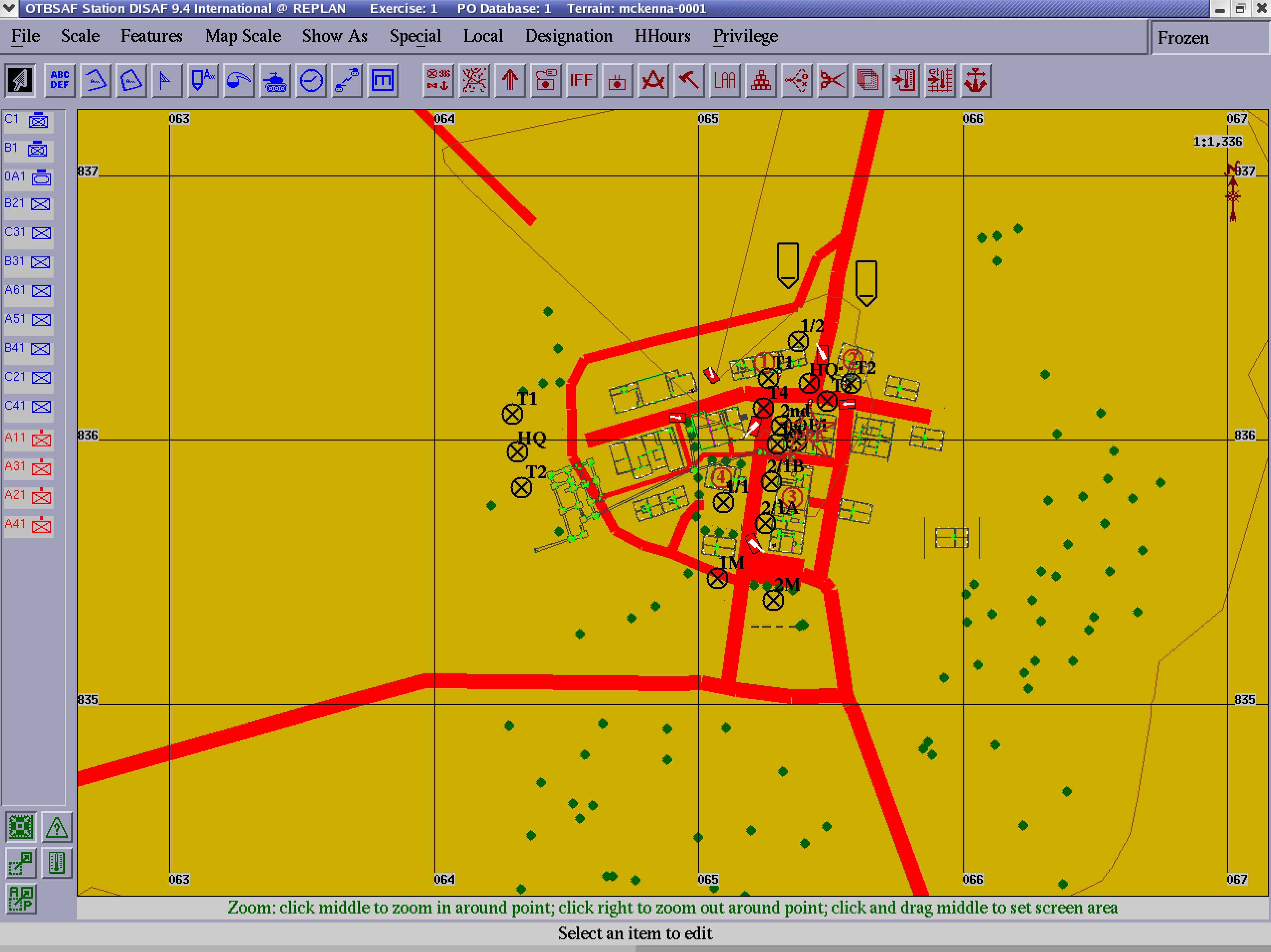
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T4
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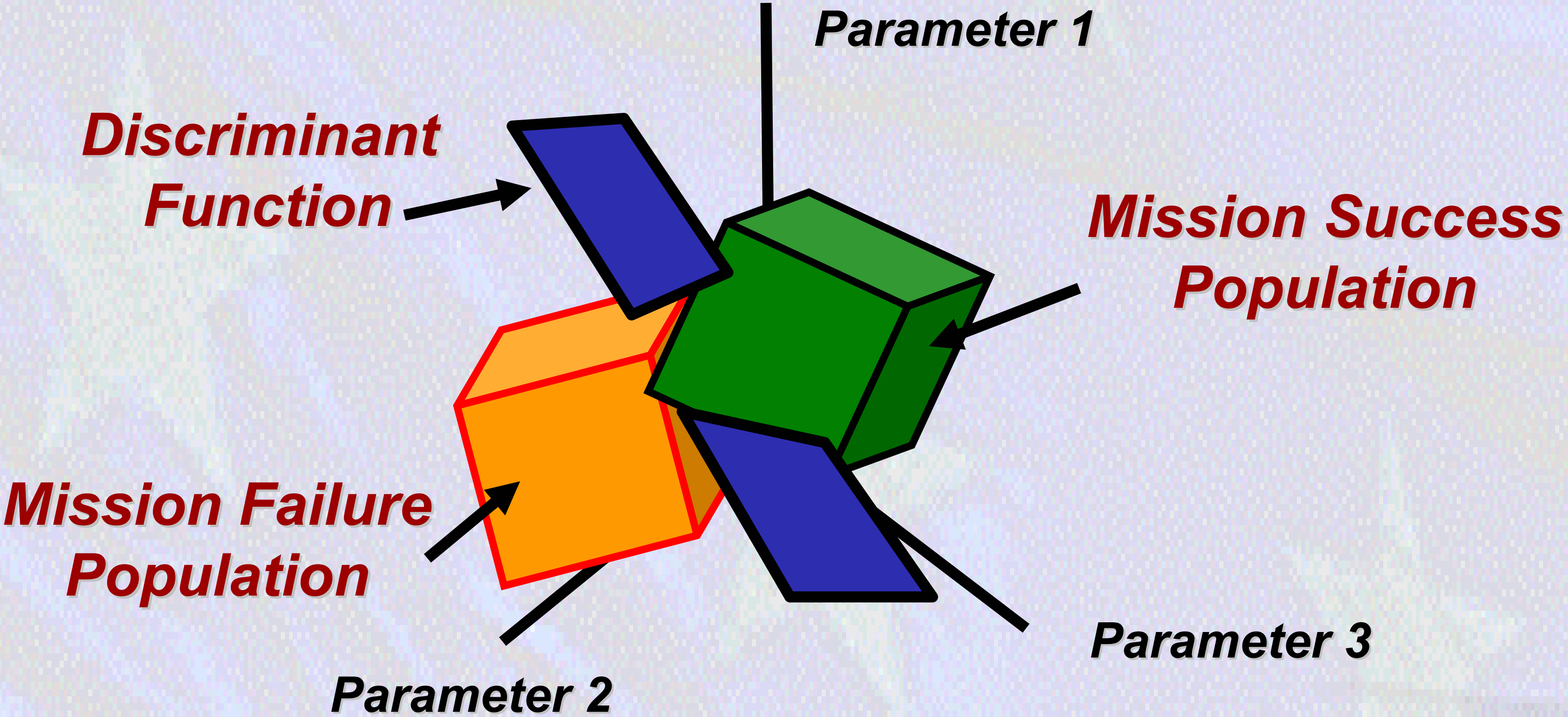
2/1A
1M
2M
Zoom: click middle to zoom in around point; click right to zoom out around point; click and drag middle to set screen area
Select an item to edit

Discriminant Analysis

- **Maximizes** $|a'(\bar{x}_1 - \bar{x}_2)| \; s.t. \; a'Sa = 1$
- **Assumes multivariate normal predictors with common covariance matrix Σ but different mean vectors μ_1 and μ_2**



Standardized Coefficients

Variable	Standardized Coefficients (FINALM for Canonical Variables		
	Root 1	Root 2	Root 3
F8TS2	-0.916437	0.127259	-0.088794
A23TS2	0.345706	0.556590	-0.246588
RTA11TS2	0.533809	0.179519	-0.411562
BMC12TS2	0.266831	-0.604834	-0.143915
F5TS2	-0.398093	0.267274	0.203862
M3T13FS2	-0.088558	-0.259234	-0.699959
M2A21TS2	-0.059910	0.218665	0.824142
Eigenval	0.791787	0.568677	0.110980
Cum.Prop	0.538102	0.924577	1.000000

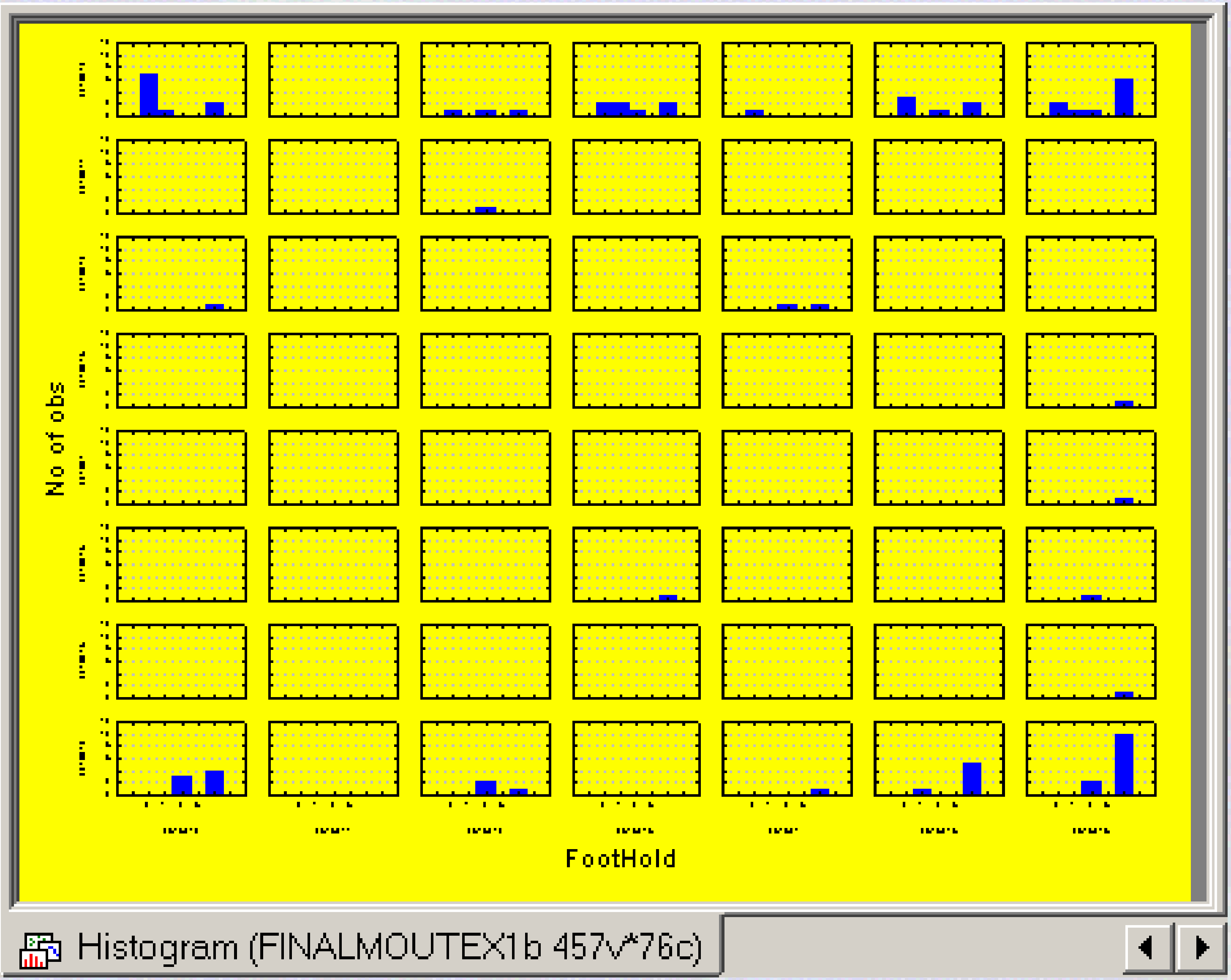
Standardized Coefficients (FINALMOUTEX1b)

Testing Roots

Roots Removed	Chi-Square Tests with Successive Roots Removed (FINA					
	Eigen-value	Canonicl R	Wilks' Lambda	Chi-Sqr.	df	p-level
0	0.791787	0.664754	0.320239	78.00018	21	0.000000
1	0.568677	0.602097	0.573799	38.05006	12	0.000151
2	0.110980	0.316060	0.900106	7.20912	5	0.205546

Chi-Square Tests with Successive Roots Removed (FINALMOUTEX1b)

FT3 (Y) by FT7 (X) by Foothold Frequency



FT5 (Y) by FT8 (X) by Foothold Frequency